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BIOMONITORING AND ASSESSMENT OF ENVIRONMENTAL CONTAMINANTS IN BREEDING COMMON TERNS (*Sterna hirundo*) OF THE ST. LAWRENCE RIVER

by
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Executive Summary

The goals of this study were to determine the nature and extent of environmental contaminant burdens in the Common Tern (*Sterna hirundo*) population of the St. Lawrence River, New York, and to evaluate the potential for negative impacts to that population. Reproductive parameters and contaminant burdens of the Common Tern population were compared to the Niagara River, Atlantic coast and Great Lakes populations.

Between 1986 and 1990, 41 Common Tern egg and 24 forage fish samples from the St. Lawrence River were collected and analyzed for organic and elemental residues. The data gathered in this study provide an excellent data base of contaminant levels upon which future monitoring can be based.

The results indicated that Common Terns were good indicators of local contamination. The results also indicated that the levels of PCBs, DDE, dieldrin, and mercury may be related to the low reproductive success of terns at some colonies and to the types and rates of abnormalities observed in chicks. Using only breeding success as an indicator of contaminant effects, there would not appear to be any relationship between the levels of contaminants and reproductive performance in terns. However, the incidence of chick abnormalities observed was comparable to those reported for an Atlantic coast population, which was heavily contaminated with PCBs. This suggests that the exposure of St. Lawrence River terns to contaminants may be causing the abnormalities observed in tern chicks. In addition, the lower breeding success of terns observed at two sites, with significantly higher levels of PCBs, DDE and dieldrin than in the third site studied, may be related to the parental neglect exhibited by adult terns. These results exhibit a pattern consistent with the research of others addressing the Great Lakes embryo mortality, edema, and deformities syndrome, which may have been demonstrated in the St. Lawrence River tern population.

Other evidence that the contaminant levels reported in this study may be impacting terns and other fish-eating birds were derived from a risk assessment. The results indicated that the levels of PCBs, DDE, dieldrin and mercury in eggs and forage fish exceeded levels that are protective of fish-eating birds.

Based on the findings of this study, several areas of additional study for the St. Lawrence River are suggested.

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INTRODUCTION

Study Background

The U.S. Fish and Wildlife Service (Service) is entrusted with the responsibility to conserve, protect and enhance fish and wildlife and their habitats for the continuing benefit of the American people. To meet this responsibility, the environmental contaminant status of the St. Lawrence River has been the subject of studies by the New York Field Office for many years. In this effort, residue analyses of Common Tern (*Sterna hirundo*) eggs and forage fish were conducted to determine the nature and extent of environmental contaminant burdens in the Common Tern population of the Upper St. Lawrence River area, and to evaluate the potential for negative impacts to that population. Reproductive parameters and contaminant burdens are compared to Niagara River, Atlantic coast, and other lower Great Lakes populations.

Several studies of fish-eating birds from the Canadian lower Great Lakes and upper Niagara River have reported organochlorine concentrations in eggs, and correlations of those contaminant levels with reproductive parameters (Gilbertson and Reynolds 1974, Frank *et al.* 1975, Fox 1976, Gilbertson *et al.* 1976, Morris *et al.* 1976, Norstrom *et al.* 1980, Mineau *et al.* 1984). Other studies have implicated or suggested environmental contaminants, particularly organochlorine compounds, as the causative agents in the reproductive failure of Herring Gulls (*Larus argentatus*) , Common Terns, Black-crowned Night-Herons (*Nycticorax nycticorax*), and Double-crested Cormorants (*Phalacrocarax auritus*) (Hays and Risebrough 1972, Fox 1976, Morris *et al.* 1976, Weseloh 1983, Mineau *et al.* 1984). In addition, an increased incidence of abnormalities among nonpasserines may be related to environmental contamination and seems to be widespread both geographically and taxonomically (Gotchfeld 1975).

In a study of fish-eating birds, Gilbertson *et al.* (1976) reported Common Terns as having the lowest recorded level of polychlorinated biphenyls (PCBs) residues in their eggs among several species, but showed the highest incidence of chick deformities. Moreover, Common Tern colonies contained the highest incidence and widest variety of chick abnormalities among the species examined. They also noted that both the incidence of abnormalities and the apparent levels of PCB and p,p'-DDE contamination were higher in Common Tern colonies in the lower Great Lakes than in those investigated by Hays and Risebrough (1972) on the Atlantic coast. These results indicate that terns exhibit physiomorphological anomalies with frequencies relative to the degree and nature of localized contamination.

To assess the impacts of toxic chemical pollution on the environment, several different groups of scientists in North America are focusing their attention on biological indicators, or biomarkers, of pollution. Indicators of pollution induced environmental stress are being identified and many studies are available where indicators have been successfully used to document the impacts of contaminants. Such studies usually take the form of comparisons between polluted and unpolluted areas where there are known discharges and existing residual pollution in the sediments. From a wildlife standpoint, indicators such as population decrease, effects on reproduction, congenital malformations, behavioral changes, and biochemical changes are being used to document the effects of toxic substances on fish and wildlife resources. These indicators, when accompanied by information on the contaminant levels in whole organisms and tissues, are leading resource managers to address the serious concerns and issues related to toxic chemical pollution in the environment.

General Description of Study Area

The St. Lawrence River is the longest east-west river on the North American continent. It is the only natural outlet for the Great Lakes, coursing a distance of 557 miles from Lake Ontario across the St. Lawrence Plain into the Gulf of St. Lawrence. The study area has within its boundaries approximately the upper 125 miles of the river. The river flow is extremely uniform because of the large natural storage area provided by the Great Lakes. At Massena, New York, the maximum daily average discharge is about 350,000 cubic feet per second. The river serves in this section as the International border: the boundary line is located between the river's shorelines.

Geology and Soils

Surface topography of the St. Lawrence River watershed is chiefly of constructive origin: mostly glacial deposition somewhat modified by a later marine overlay, and more recently modified by stream dissection. The relief is characterized by a somewhat erratic distribution of hills and sometimes ridge-like elevated portions with either irregular or valley-like depressions. These features generally exhibit a moderate relief, reaching a maximum of less than 150 feet above area water levels. Because of this relief pattern, the upper St. Lawrence River has numerous islands; a section of the upper river area is commonly referred to as the "Thousand Islands".

The soils of the St. Lawrence region are diverse. They are strongly influenced by glaciation and a relatively high seasonal water table. The soil types vary from dense, poorly drained clay and silty clay soils (Jefferson County) to rapidly permeable sands and fine sandy loams (upper St. Lawrence County). The soil is principally of sedimentary origin resulting from the deposition of glacial drift or of water-laid sediments. The soils are often shallow and directly on bedrock, particularly in Jefferson County. St. Lawrence County soils are generally sandier, deeper, and often deposited on glacial till.

Vegetation

Successional fields occupy 22% of the shoreline areas along Lake Ontario and the St. Lawrence River in Jefferson and St. Lawrence Counties, New York. Although forests cover 10% of Jefferson County and 23% of St. Lawrence County, evidence of past use and abuse is abundantly present. Relatively undisturbed forests are rare. Fragile communities, sensitive to human impact, occur on rock outcrops, wetlands, and sand dunes. Unique vegetational areas are found where rare species or habitat types persist. Other habitat types, although not unique, are of high importance for the maintenance of the environmental quality of the region.

Fisheries Resources

The St. Lawrence-Eastern Lake Ontario region harbors a major portion of the fisheries of New York State. Sport fishing supports a multimillion dollar industry annually.

Fisheries of the region are characterized by both warmwater and coldwater stocks. Coldwater fish, such as coho (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tshawytscha*) have been introduced into Lake Ontario and, along with rainbow (*Oncorhynchus mykiss*) and lake trout (*Salvelinus namaycush*), have developed into a substantial fishery.

Smallmouth bass (*Micropterus dolomieui*) is the most important warmwater species from the viewpoint of angler preference, economics, and catch. Northern pike (*Esox lucius*) is second in preference followed by yellow perch (*Perca flavescens*), rock bass (*Ambloplites rupestris*), and muskellunge (*Esox masquinongy*).

The St. Lawrence River shoreline region contains approximately 7,000 acres of wetland resources in New York State. The resources contain many highly productive fisheries areas such as the Raquette, Grass, and Oswegatchie Rivers, Coles Creek, Chippewa Creek and marsh, Crooked Creek and marsh, Cranberry Creek and marsh, and the wetlands of Grindstone and Wellesley Islands.

Wildlife Resources

The St. Lawrence region contains a substantial diversity of wildlife species. It supports a wide-range of species which require aquatic habitats for survival including some Federal and State listed endangered and threatened species. Most notably these include fish eating species such as the Bald Eagle (*Haliaeetus leucocephalus*), Common Tern (*Sterna hirundo*), Osprey (*Pandion haliaetus*), Common Loon (*Gavia immer*), and Black Tern (*Chlidonias niger*). Other fish eating species which use the St. Lawrence region include colonial nesting species such as the Caspian Tern (*Sterna caspia*), Double-crested Cormorant (*Phalacrocorax auritus*), Ring-billed Gull (*Larus delawarensis*), Herring Gull (*Larus argentatus*), and Great Blue Heron (*Ardea canadensis*). The largest rookery of Great Blue Herons in northern New York is located on Ironsides Island.

The region's lowlands and marshes are important for both the harvest and production of many species of dabbling and diving ducks. During migration, over 20% of New York's migrating waterfowl population uses the St. Lawrence River. The total avian resource concentration, particularly in the spring, gathers from all over eastern North America and many parts of South America. During spring migrations, birds are hesitant to cross wide bodies of water, and thus, detour around the eastern shore of Lake Ontario. Many of the transient birds funnel into a narrow stretch bounded by Lake Ontario on the west and the Tug Hill-Adirondack uplands on the east, dispersing after reaching the St. Lawrence River.

The marshes of the St. Lawrence River and tributaries produce large numbers of valuable furbearers (e.g. muskrats (*Ondatra zibethica*), beaver (*Castor canadensis*), mink (*Mustela vison*), and raccoon (*Procyon lotor*)) that are important sources of recreational pleasure and economic return through trapping. Significant acreage of undeveloped, privately-owned wetlands with high wildlife potential also exist along the St. Lawrence Plain.

Recreational Resources

Many attractions exist for the recreationist in the St. Lawrence River-Eastern Lake Ontario region of New York. The basic attractions are those provided by the region's natural setting: its waters, islands, fish, wildlife, and visual contrasts of the topography, vegetation, and rock at the water's edge.

The waters of the lake and river are the major unifying factor of the region. Active recreational use of the water includes boating (motor, sail, or paddle), water-skiing, fishing, ice fishing, waterfowl hunting, trapping, snowmobiling, and swimming. Indirect recreational water uses involve sightseeing at vantage points along the shore or driving along shoreline highways where the water is visible. Other leisure time activities including sunbathing, strolling, camping, picnicking, bicycling, horseback riding, golfing, nature study, birdwatching, and wildlife photography are concentrated along the river. The "Thousand Islands" area provides a particularly unique recreational attraction and strongly supplements the appeal of the water itself.

Shoreline Development

Over 60% of the U.S. mainland shoreline has already been developed. The shoreline areas nearest the water have the most development. Frequently this development has occurred no more than 200 to 300 feet inland, with the surrounding area remaining either agricultural or undeveloped and wild. This trend appears very likely to continue at a rapid rate.

In New York State, major resort centers along the St. Lawrence River are Cape Vincent, Clayton, Alexandria Bay, and Thousand Island Park. These centers contain public and private recreational facilities. These areas have taken the heaviest developmental pressure.

Ogdensburg and Massena are urbanized areas. The main economy of Massena is heavy industry resulting from construction of the Moses-Saunders Power Dam. There, the New York Power Authority supplies power to Reynolds Metals Company, General Motors Corporation, and ALCOA.

STUDY SITES

Selection of study sites was based on the physical and biological characteristics at the colonies, their proximity to gull colonies, and the availability of information on the history of predation, site use for nesting, and colony size.

Common Terns nesting at the Eagle Wing Islands, Gull Island and Navigation Aid N-156 were selected for study. The Eagle Wing Islands are part of a five member group of small rock outcroppings located in the river north of Clayton, New York (Fig. 1). They are composed of granitic gneiss overlain with patches of very shallow, low lime, loamy soil (McDowell 1989) that has accumulated in the cracks and depressions of the rock. Vegetation typically grows in areas where soil accumulated and includes; common ragweed (*Ambrosia artemisiifolia*), common dandelion (*Taraxacum officinale*), aster (*Aster* sp.), three-leaf cinquefoil (*Potentilla norvegica*), lady's thumb (*Polygonum pericaria*), and grass (*Poa* sp.). Both Eagle Wing Islands orient roughly east-west with about a 45 degree incidence to the prevailing winds. Island relief differs between the sites. Eagle Wing Island-1 rises gently from water level on the east end to a maximum height of about 2.5 m on the west end. Eagle Wing Island-2 rises gently from all sides to a maximum height of about 1 m. Despite fluctuations in water levels their dimensions change little, but they are prone to some over-spraying and wash-over from waves generated during strong winds.

Gull Island is also a small, granitic outcropping located about 3 km east of Clayton (Fig. 1). The island topography consists of two distinct areas. The southern end of the island, which covers nearly one third of the total area, rises abruptly above the water level to a maximum height of about 6 m, and can best be described as a flattened dome. The remainder of the island is relatively flat, rising about 1.5 - 2.0 m above water level, and slopes gently to the water at the edges. The central portion of the island and the top of the "dome" are covered with a contiguous sheet of thin soil (approx. 4 cm). In addition, small patches of soil occur in cracks and depressions in the remaining areas of the island. Vegetation on the island includes; cottonwood (*Populus deltodies*), purple-flowering raspberry (*Rubus odoratus*), wild potato vine (*Ipompea pandurata*), grass (*Poa* sp.) common St. Johnswort (*Hypericum perforatum*), staghorn sumac (*Rhus typhina*), blueberry (*Vaccinium* sp.), red-osier dogwood (*Cornus stolonifera*), tartarian honeysuckle (*Lonicera tatarica*), black elderberry (*Sambucus canadensis*), bitter nightshade (*Solanum dulcamara*), and rose (*Rosa* sp.). Because of its position in the river relative to other islands and its steeper slope to the waters edge, Gull Island is not exposed to wave generated over-spray or wash-over as is the Eagle Wing Islands Group. Navigation Aid N-156 is owned and maintained by the U.S. Department of Transportation, St. Lawrence Seaway Development Corporation, Massena, New York. N-156 is located in the Chippewa Bay area (Fig. 1). The structure stands on the river bottom creating a small island. The site consists of a cylindrical steel base 8 m in diameter that is partially filled with dredged river sediment, and a metal scaffolding that supports a navigation instrument. The surface is approximately level (forming a platform) with the upper rim of the base located about 2.5 m above mean water level. The height of the upper rim from the core substrate is about 5 cm. A 5 m tall scaffolding is located at the center of the marker.

Vegetation uniformly covers the surface of the navigation aid and includes purple-flowering raspberry (*R. odoratus*), bladder campion (*Silene vulgaris*), white sweet clover (*Melitolis alba*), lamb's quarters (*Chenopodium alba*), common ragweed (*A. artemisiifolia*), butter-and-eggs toadflax (*Linaria vulgaris*), roadside peppergrass (*Lepidium ruderale*), and wild potato vine (*I. pandurata*).

METHODS

Egg collections

A total of 41 Common Tern eggs were collected from randomly selected nests during the summers of 1986, 1987, 1988, and 1989. In 1989, five samples consisting of two egg composites were collected from Oneida Lake. Oneida Lake is a relatively clean site in central New York State used in this study as a reference site for comparison purposes. To reduce sampling bias, only the third eggs laid in a clutch, incubated less than eight days, were collected. The laying sequence was determined by visually comparing eggs in a clutch. The smallest egg was assumed to be the last egg laid. Stage of incubation was estimated by the flotation method described by Hays and LeCroy (1971). As eggs were taken from each nest, they were wrapped in aluminum foil, placed in an egg carton, and stored in a cooler packed with "blue ice" until returned to the laboratory. Eggs not processed the same day were refrigerated for no more than three days before they were prepared.

<u>Forage fish collections</u>

To determine the fish species eaten by Common Terns, observations were made of foraging adults, the feeding of chicks, and chick regurgitations. Fish dropped in the colonies were also collected. The fish identified as tern forage species were collected from areas used by feeding terns with pull seines and hoop nets. Captured fish were emptied directly from the nets into hexane rinsed aluminum foil, wrapped, and stored on ice until processed in the laboratory. Composite samples of each species were prepared in the laboratory and stored frozen until they were processed by the analytical laboratories.

<u>Breeding success of Common Terns</u>

Common Terns breeding in the St. Lawrence River were studied in 1987 and 1988. Between mid-May and mid-July, colony sites were visited every 1-4 days. All nests were marked with a numbered marker and a detailed chronology was kept for a subsample of randomly selected nests and their contents until the last egg hatched or the nesting attempt failed. To keep chicks from jumping off colony sites, 30 cm high, 2.54 cm hexagonal mesh wire fences were erected around study plots prior to the commencement of hatching.

For this study hatching success and fledging success were used to measure the relative overall breeding success of the Common Terns. Hatching success was defined as the number of eggs hatched per egg laid per nest. During the hatching period, chicks were banded within two days of hatching with a Service, Size 2, aluminum leg band. At the time of banding, each chick was examined for external abnormalities of the eyes, bill, feet and legs and feather tracts, and the result noted. This banding schedule allowed chicks to be identified with a specific nest. Chick survival was determined on each visit by comprehensively searching the colony and recording the band number of each chick encountered. Chicks that were not encountered on a given visit were usually encountered (more than 96%) during the next visit. Unless chicks were found during later visits, they were considered to have been depredated. Chicks alive more than 10 days were considered to have fledged. Information on the history of each chick was collected until the chick died, disappeared, or fledged. Fledging success, like hatching success, was calculated on a per nest basis. Fledging success was defined as the number of chicks fledged per egg hatched per nest.

Sample preparation and analytical procedures

Bird egg and fish sample preparations were conducted as outlined in Appendix A. In 1986, tern egg samples consisted of 2 or 3 egg composites, whereas, in 1987-1989 each egg sample consisted of 2 eggs. Quality assurance/quality control (QA/QC) for the analytical techniques used by the contract laboratories were established and overseen by the Service's Patuxent Analytical Control Facility (PACF).

Statistical methods

Mean contaminant concentrations are reported in parts per million (ppm) wet weight for organic residues and ppm dry weight for elemental residues for each sample when at least half of the samples had detectable levels of contaminants. For this report, a value of one-half the detection limit was assigned to samples in which no residues were detected. Residue concentrations were log transformed before statistical analysis and the retransformed means are presented in the tables. Organochlorine and elemental concentrations in Common Tern eggs were compared between sample sites by the Mann-Whitney Test. Means that were not significantly different at $\alpha=0.05$ were pooled for subsequent analyses. Contaminant levels in Common Tern eggs among years were compared by analysis of variance. Multiple comparisons among years were made by the Bonferroni method (Sokal and Rohlf 1981).

RESULTS

A total of 41 Common Tern eggs and 24 forage fish samples were collected for this study. Summary data on egg measurements for tern eggs are listed in Table 1. Data summarizing forage fish sample measurements are listed in Table 2.

Organochlorine residues

For the St. Lawrence River samples, PCBs and dieldrin were detected in every Common Tern egg sample for all years. p,p'-DDD, mirex, hexochlorobenzene (HCB), and heptachlor epoxide were detected for all but one year (Table 3). Seven other compounds were detected in three of the detected in three of the four years eggs were collected. With the exception of PCBs, p,p'-DDE, and mirex, compounds were present at low concentrations, in the range of a few hundredths of a ppm. Maximum concentrations of PCBs, p,p'-DDE, and mirex were 9.6, 3.1, and 0.61 ppm, respectively. DDE:PCB ratios for bird eggs and forage fish are summarized in Table 4. In 1988, a peak year for many of the contaminants analyzed for, five organochlorines where significantly higher in samples from Clayton than from Chippewa Bay (Table 6). The geometric mean concentrations and 95% confidence intervals of organochlorine residues in eggs are summarized in Table 5. A comparison of mean concentrations of organochlorine and aliphatic hydrocarbon residues in eggs from Clayton and Chippewa Bay is provided in Table 6.

In forage fish, only p,p'-DDE was detected in all samples. PCBs were detected in three of four years fish were sampled. Both p,p'-DDD and trans-nonachlor were detected at a maximum concentration of 0.01 ppm (Table 7). Maximum concentrations of PCBs and p,p'-DDE were 0.36 and 0.06 ppm, respectively. Geometric mean concentrations of organochlorine residues in forage fish are provided in Table 8.

Metal and trace element residues

For tern eggs collected from the St. Lawrence River, concentrations of six elemental residues were detected in all eggs in all years of the study (Table 9). Aluminum was detected in three of four years of sampling. Cadmium and chromium were detected at low levels in two years, and beryllium was detected in 1986 near its level of detection. Magnesium and strontium were analyzed in 1989 only. Maximum concentrations of mercury, selenium, and copper were 2.54, 3.56, and 4.11 ppm, respectively. Lead was detected in less than half of the tern eggs collected in every year. Geometric mean concentrations and 95% confidence intervals of elemental residue concentrations in tern eggs are summarized in Table 10.

For egg samples collected at Oneida Lake, nine elements were detected in more than half of the samples analyzed (Table 9). Maximum concentrations of mercury, selenium, copper, and strontium were 1.69, 3.39, 6.61, and 1.00 ppm, respectively. In a comparison of mean elemental concentrations for egg samples from Clayton and Chippewa Bay, mercury and strontium content were significantly higher in fish collected from Chippewa Bay than Clayton (Table 13). Geometric mean concentrations and 95% confidence intervals of elemental residue concentrations in Oneida Lake Tern eggs are provided in Table 10.

Forage fish had detectable levels of 14 elemental residues in over half of the samples collected (Table 11). Geometric mean concentrations and 95% confidence intervals of elemental residue concentrations in forage fish are provided in Table 12. A comparison of mean concentrations of mercury and strontium in forage fish collected from Clayton and Chippewa Bay is presented in Table 13. Arsenic, cadmium, chromium, and nickel had detectable levels in three of four years. Magnesium and strontium were only analyzed in 1990. The remaining seven elements were detected in every year. Maximum concentrations of mercury, selenium, and copper were 0.29, 8.00, and 11.0 ppm, respectively. Cadmium and arsenic were detected at low levels. Maximum concentrations of aluminum, nickel, and chromium were 379.0, 153.0, and 4.2 ppm, respectively.

Aliphatic and aromatic hydrocarbon residues

Aliphatic and aromatic hydrocarbon compounds were analyzed in 1986-1988. The majority of Common Tern egg samples collected between 1986 and 1988 had concentrations of aliphatic hydrocarbons below the level of detection, or measuring a few hundredths of a ppm (Table 14). Eleven aliphatic hydrocarbons were detected in 1988 and three were detected in 1986. None were detected in 1987. Between 1986 and 1988, aromatic hydrocarbons were below the level of detection (0.01 ppm) in more than half of the samples analyzed. Geometric mean concentrations of aliphatics are summarized in Table 5.

Breeding success, deformities, and risk assessment

Hatching success, the number of eggs hatched per egg laid per nest, in 1987 for sites N-156, Eagle Wing Island-2, and Gull Island was 0.96, 0.70, and 0.77, respectively. In 1988 hatching success was 0.96 and 0.00 for N-156 and Eagle Wing Island-2, respectively. Fledging success, the number of chicks fledged per egg hatched per nest, for site N-156 in 1987 and 1988 was 0.90 and 0.94, respectively. Breeding success for the same years was 2.54 and 2.79, respectively. In 1987 fledging success was 0.13 at Eagle Wing Island-2 and 0.10 at Gull Island. Breeding success, the number of chicks fledged per total number of nests, in the total St. Lawrence River population was 0.92 and 1.4 for 1987 and 1988, respectively.

Two types of chick deformities were observed between 1986 and 1990. In 1986 and 1987, the abnormalities consisted of curved mandibles and in 1990 of deformities of the toes. The percent prevalence of chick deformities in 1986, 1987, and 1990 were 0.40, 0.25, and 0.22, respectively.

Levels of several organochlorines and mercury exceed the no observed adverse effect level (NOAEL) and lowest observed adverse effect level (LOAEL) reported for sensitive species. Contaminant risks to Common Terns and other fish-eating bird species are contained in the risk assessment provided in Appendix B.

DISCUSSION AND CONCLUSIONS

Organochlorine (OC) contamination in St. Lawrence River and Oneida Lake Common Terns is considered low and does not appear to impair their reproduction. Maximum concentrations of the most prevalent OCs are PCBs(9.6 ppm), p,p'-DDE(3.3 ppm), and mirex(0.61 ppm). These concentrations are lower than those reported to affect reproduction in Common Terns elsewhere (Custer *et al.* 1983).

Among the OCs found in the tern eggs, p,p'-DDE is most often associated with eggshell thinning (Radcliffe 1967, 1970, Longcore *et al.* 1971, King *et al.* 1978, Blus 1982). PCBs are thought not to affect eggshell thickness (Peakall 1975). The mean eggshell thicknesses of Common Tern eggs collected between 1986 and 1989 were in the range of those measured by Custer *et al.* (1983) for Atlantic coast Common Terns and by Weseloh *et al.* (1989) for Common Terns of the Canadian Great Lakes. Neither investigator found a significant correlation between p,p'-DDE concentrations in Common Tern eggs and eggshell thickness. Additionally, Common Tern eggshell thickness and structure are not seriously affected until mean p,p'-DDE levels exceed 4 ppm in eggs (Switzer *et al.* 1973, Fox 1976). The maximum concentration of p,p'-DDE detected in this study was 1.6 ppm.

The concentrations of elemental residues of greatest toxicological concern that were detected in tern eggs, also appeared to be lower than those generally thought to affect reproduction. In particular, mercury, selenium, and chromium levels (maximum concentrations: 2.54, 3.56, and 0.84 ppm dry weight, respectively), were below those thought to affect reproduction in birds (Fimreite 1971, Eisler 1985, 1986, 1987).

The high levels of nickel found in the 1988 forage fish samples were not consistent with other data collected by the Service and are likely the result of sample contamination. A similar but also unusually high nickel level occurred in a 1988 fish sample from another study conducted by the New York Field Office.

Mean concentrations of PAHs and aliphatics, when detectable, were usually a few hundredths to a few tenths of a part per million. For PAHs, these results are difficult to interpret since information on the toxicology of PAHs on avian wildlife is scarce. Hoffman and Gay (1981) measured the embryotoxicity of various PAHs to Mallards (*Anas platyrhynchos*) and reported that a concentration of 0.002 ug/kg/egg of one of the most toxic PAHs, 7,12-dimethylbenz(a)anthracene, caused 26% mortality in 18 days. Survivors showed an increased incidence of skeletal, eye, brain, liver, feather and bill deformities, and a reduction in embryonic growth. At 0.01 ug/kg/egg, only 10% of the embryos survived to day 18. Another factor which complicates the interpretation of exposures of birds to low concentrations of PAHs, is that embryos may contain more microsomal enzymes than adults which can metabolize PAHs to more highly toxic intermediates. Avian embryos also have a greater capacity than mammals to bioactivate PAHs.

As with PAHs, the aliphatic hydrocarbon levels found in this study do not appear to pose a significant toxicological threat to the Common Terns studied. Much of the work done on the biological effects of petroleum hydrocarbon (PH) ingestion indicate that adult birds tolerate oil in the diet reasonably well. However, a variety of biochemical, physiological, and other changes may occur, such as depression of growth, impaired avoidance behavior, liver lesions, splenic atrophy, kidney degeneration, biochemical lesions, and depressed egg production. Bird embryos are at greater risk of PH toxicosis. Couillard and Leighton (1991) found that petroleum levels as low as 3.6 μl/egg induced liver necrosis and edema in chicken embryos. Therefore, it is likely that PH toxicity is dependent on the life stage and environmental stresses that the organism experiences at the time of exposure. Although indications of gross toxicological injury from PHs was observed, Hall and Coon (1988) concluded that since most animals in nature are subjected to stresses such as reproduction, migration, and overwintering, any decline in physiological fitness resulting from contaminant exposure could result in corresponding effects in the population.

The usefulness of an indicator species in assessing contaminant exposures and health risks depends largely upon how well the species reflects the character of local contamination, and the extent to which it exhibits a response to toxicological insult. In this study, Common Tern eggs reflected local levels rather than contamination obtained on the terns' wintering grounds. They also may have exhibited a response to relatively low levels of contaminant exposure. Several lines of evidence support these conclusions.

First, it was hypothesized that the pattern of contaminant uptake in forage fish collected from the St. Lawrence River would be indicative of local contamination and that the DDE to PCB ratio in tern eggs would not be significantly different than the ratio in forage fish, since the tern's diet is primarily fish (> 90%). Not only were the DDE to PCB ratios nearly the same for eggs and forage fish for each year of study, but the ratios show the same pattern of decline of contaminant concentrations over the study period (Table 4). Secondly, another hypothesis was that the DDE to PCB ratio for St. Lawrence River samples would be lower than those for Oneida Lake samples since contaminant inputs to the St. Lawrence River are expected to be higher than those for Oneida Lake. Additionally, it was expected that levels of mirex would be greater in St. Lawrence River samples than in Oneida Lake samples, since the origins of mirex contamination in the region are primarily restricted to Lake Ontario. In both cases the reported values were consistent with these hypotheses. Moreover, several studies (e.g. Ohlendorf *et al*. 1978, Custer *et al*. 1983, Fasola *et al*. 1987, Weseloh *et al*. 1989, Karwowski 1991) have also attributed organochlorine concentrations in eggs of breeding Common Terns to be of local origin and not from their wintering grounds. Together, these findings support the hypothesis that the Common Tern was a good monitor of environmental contaminants in the St. Lawrence River.

Despite the low concentration of contaminants found in the bird egg and fish samples from the St. Lawrence River, Common Terns experienced low hatching, fledging and breeding success at Eagle Wing Island-2 and Gull Islands in 1987 and 1989. Low hatching success due to egg loses dominated the Eagle Wing Islands colony failure, whereas, chick depredation was largely responsible for the low breeding success at Gull Island. Hatching, fledging, and breeding success at N-156 was significantly higher in both years and was attributed to the absence of predation at the site. Similar results were reported for several St. Lawrence River Common Tern colonies by Karwowski *et al*. (In Review). A traditional interpretation of the results in this study would dismiss the idea of any causal relationship between the contaminant levels and the reproductive performance reported. However, when the patterns of contaminant levels, chick deformity rates, and breeding success are scrutinized more closely in relation to one another and the findings of other studies; Common Terns and other fish-eating wildlife, are possibly being adversely impacted by PCBs, DDE, dieldrin and mercury.

Although this study was not designed to examine specific relationships among contaminant levels and endpoints, several striking similarities with other studies exist. First, the results of this study are consistent with the findings of Hays and Risebrough (1972) in their study of contaminant levels and abnormalities in terns from the Atlantic coast. Both the levels of PCBs, DDE and mercury, and the rates of deformities in chicks were generally consistent with those found in this study. Moreover, the types of abnormalities recorded in these studies matched those produced in experiments with young chickens dosed with selected PCBs and chlorinated dibenzo-p-dioxins. A difference between the studies was that the maximum concentration of PCBs in a small proportion of the samples in the Hays and Risebrough study were substantially higher than in this study. The significance of this difference is difficult to assess since total PCBs, not specific isomers were reported. However, the difference is not likely to be important, since it may be related to the nature of the physicochemical degradation processes that PCBs undergo and the relative toxicities of the individual congener components that makeup the total PCBs. Unlike the coplaner and higher molecular weight congeners, many of the lower weight and non-dioxin like PCBs tend to undergo degradation more rapidly. Since the restriction of their use in 1972, one would expect total PCB levels to decline and that a higher proportion of the more toxic congeners would make up the total PCBs found in tissue. This conclusion is supported by the types and rates of abnormalities observed in this study and by Hays and Risebrough (1972), regardless of the difference in maximum PCB levels found. This interpretation is also consistent with the observation that all dioxin-like PCBs are embryotoxic (teratagenic and mutagenic), whereas, the non-dioxin like PCBs have yet to be implicated in the manifestation of physical abnormalities in wildlife (Kubiak, person. comm.).

Similarities of results and observations in this study with the study of behavioral abnormalities in gulls by Fox *et al*. (1978) and those discussed in the review by Rattner *et al*. (1984) also support the conclusion that the levels of contaminants in tern eggs and forage fish found in this study are causing negative impacts to terns and other fish-eating wildlife. Although the unraveling of any causal relationship between contaminant levels and reproductive performance in terns went beyond the scope and methodology of this study, certain patterns of exposure and response begin to emerge from the data.

First, in 1988, a year of concentration peaks for many contaminants, levels of five organochlorine compounds (including PCBS, DDE and dieldrin) and two petroleum hydrocarbons were significantly higher in eggs collected from Clayton than from Chippewa Bay. Secondly, the breeding success of terns nesting in Clayton was significantly lower than for those nesting in

Chippewa Bay in this study and in a study by Karwowski *et al.* (In Review). In both studies, the lower reproductive performance in the Clayton area was attributed to a difference in nest attentiveness, which was absent at Chippewa Bay. These results suggest that a relationship exists between contaminant levels and breeding success. However, the occurrence of differential predation at the study sites and its effect on the breeding success of terns, complicates the interpretation of the results. Given the differences in contaminant burdens between the sites, was it solely the observed presence versus absence of predation in the two areas studied that accounted for the difference in breeding success? Or, was there a difference in behavioral response to predation by adult Common Terns, mediated by contaminant burdens, that resulted in the difference in breeding success between the study sites?

Several lines of evidence support the latter, that abnormal behavior, such as parental neglect, resulted from a pollution-induced endocrine dysfunction. Fox *et al.* (1978) stated that the behavioral abnormalities they observed in nesting, Lake Ontario, Herring Gulls probably resulted from a pollution-induced endocrine dysfunction. They based their conclusion on a comparison of nest defense and incubation behaviors between colonies of PCB contaminated gulls in Lake Ontario with those at two control sites. The control sites, one in Lake Huron and one in New Brunswick, were considered to have low contaminant burdens. For both behaviors, gulls in Lake Ontario were less attentive than those at the control sites. Furthermore, the total organochlorine content of single egg samples taken from Lake Ontario nests were positively correlated with the total time eggs were not incubated.

Additional support for the interpretation that Common Terns are being impacted by their exposure to St. Lawrence River contaminants, is found in Rattner *et al.* (1984) and Gilbertson *et al.* (1991) . In their paper regarding avian endocrine responses to environmental contaminants, Rattner *et al.* highlighted the relationship of a number of chlorinated hydrocarbon compounds, in particular DDT, DDE, PCBs, and mirex, as being associated with hormonal changes that have experimentally induced behavioral anomalies such as parental neglect, abnormal courtship and nest construction, and altered breeding synchrony. Since the predominant organochlorine compounds and observations of parental neglect from this study match those discussed by Rattner *et al.*, it follows that the reduction in breeding success in Clayton terns may have resulted from a contaminant-induced endocrine dysfunction.

In conjunction with the likelihood of endocrine dysfunction in St. Lawrence River Common Terns, the types and rates of deformities observed in chicks

In conjunction with the likelihood of endocrine dysfunction in St. Lawrence River Common Terns, the types and rates of deformities observed in chicks during this study formed a pattern resembling the syndrome in colonial fish-eating birds described by Gilbertson *et al.* (1991). In addition to the more traditional indicators of reproductive impairment used to assess toxicological insult, they described a syndrome consisting of reproductive impairments characterized by high embryonic and chick mortality, edema, growth retardation and deformities that was demonstrated in the Great Lakes Basin. This syndrome is called the Great Lakes embryo, edema, and deformities syndrome (GLEMEDS). Although all of the specific endpoints used as indicators of contaminant exposure and response that would confirm the occurrence of GLEMEDS in St. Lawrence River Common Terns were not studied, enough of the symptoms associated with GLEMEDS (abnormal nest defense and incubation behavior, and the occurrence of deformities) were observed to suggest that terns may be demonstrating the syndrome.

Finally, the results of the risk assessment (App. B) for breeding St. Lawrence River Common Terns further supports the interpretation that the tern population, and most likely other fish-eating wildlife in the St. Lawrence River, are being impacted by environmental contaminants. In a comparison of PCBs, DDE, dieldrin and mercury levels found in this study with no observed adverse effect levels (NOAELs), determined under controlled experimental conditions, all egg samples collected between 1986 and 1989 exceeded the NOAELs. Furthermore, the lowest adverse effect level (LOAEL) for DDE in St. Lawrence River tern eggs was exceeded in three of four years, and the LOAEL for dieldrin was exceeded in one year (Table B2). These results are remarkable since the risk assessment model used is a conservative one and does not account for any additive effects of the compounds modeled.

SUMMARY

1. The nature and extent of environmental contaminants in Common Terns were determined.

2. Breeding success of terns nesting in Clayton was significantly lower than for those in Chippewa Bay. The difference in breeding success may have been due to parental neglect induced by contaminants.

3. Levels of PCBs, DDE and dieldrin were significantly higher in terns from Clayton than from Chippewa Bay, whereas mercury was higher in Chippewa Bay.

4. Based on a comparison of DDE to PCB ratios and on a comparison of selected contaminant levels between terns and forage fish from the St. Lawrence River, terns were found to be good indicators of local contamination. The same comparison between terns from the St. Lawrence River and Oneida Lake support this finding.

5. The deformity rate in tern chicks was comparable to that found in an Atlantic coast population located in a PCB contaminated area.

6. The higher levels of PCBs, DDE and dieldrin, the lower breeding success of Clayton terns, and the deformities observed in this study, may demonstrate the occurrence of the Great Lakes embryo mortality, edema, and deformities syndrome.

7. A biomarker study is needed to determine the specific impacts to terns and other fish-eating wildlife that are likely to be occurring in the St. Lawrence River. The study should include:

    a. The determination of dioxin-like PCB levels in St. Lawrence River terns,

    b. a detailed study of behavioral responses in relation to contaminant levels (specifically for PCBs, DDE organophosphate insecticides and mercury) and,

    c. the collection of data on the occurrence of embryonic and chick mortality, embryonic chick growth retardation, edema, and deformities in terns.

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PERSONAL COMMUNICATION

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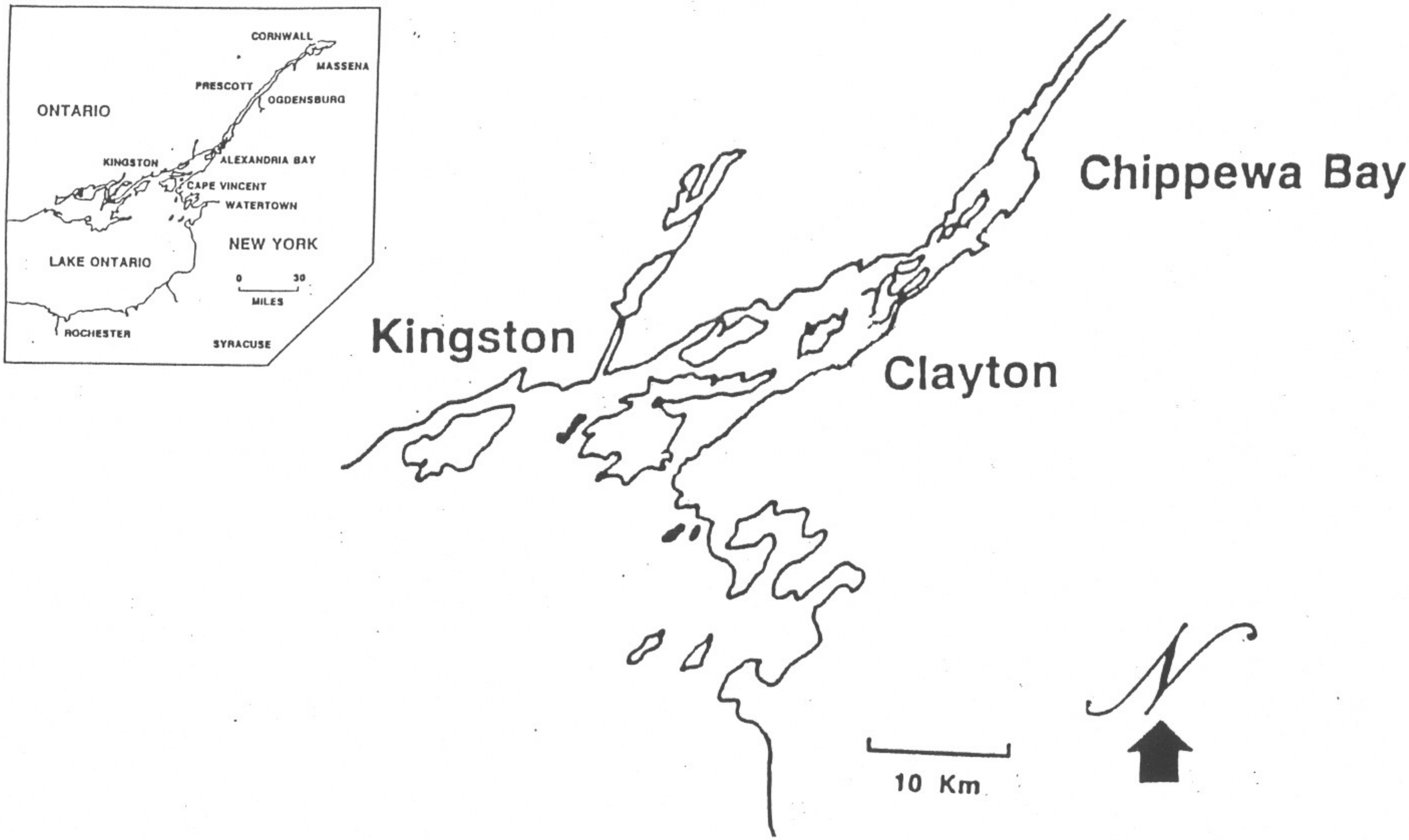

Figure 1. Locations of egg and fish collection sites in the St. Lawrence River Study area.

Table 1. Mean (±SD) egg measurements of Common Terns nesting in the St. Lawrence River and Oneida Lake, New York.

	St. Lawrence River				Oneida Lake
Compound	1986 (n=21)	1987 (n=22)	1988 (n=20)	1989 (n=10)	1989 (n=10)
Volume (mL)	20.6 ± 1.451	20.1 ± 1.434	21.2 ± 0.980	22.28 ± 0.937	20.88 ± 1.311
Whole egg mass (g)	20.53 ± 1.449	20.88 ± 1.469	20.61 ± 0.896	21.38 ± 1.192	20.31 ± 1.253
Percent lipid	8.32 ± 0.773	9.34 ± 0.450	9.85 ± 0.578	8.7 ± 0.537	10.07 ± 0.550
Percent moisure	7.69 ± 0.085	7.64 ± 0.100	7.64 ± 0.131	8.34 ± 0.337	7.64 ± 0.052
Shell thickness (mm)	0.201 ± 0.006	0.201 ± 0.009	0.202 ± 0.007	0.203 ± 0.004	0.192 ± 0.006

Table 2. Forage fish sample descriptions collected from the St. Lawrence River, New York, 1986 - 1990.

Sample I.D.	Species	Sample Mass (g)	Percent moisture	Percent lipid	Number of fish	Sample Location[a]
CFO-FF-87-3	*Notemigonus chrysolecus*	78.0	76.5	2.00	-	Clayton
CFO-FF-87-4	*Notropis hudsonius*	73.0	78.0	2.08	-	Clayton
CFO-FF-87-1	*Fundulus diaphanus*	54.15	77.9	1.40	45	Clayton
CFO-FF-87-2	*Notemigonus chrysolecus*	51.1	78.0	1.14	9	Clayton
CFO-FF-87-5	*Perca flavescens*	253.7	75.5	3.22	47	Clayton
CFO-FF-87-6	*Pimephales notatus*	43.85	77.5	1.65	26	Clayton
CFO-FF-87-14	*Perca flavescens*	59.75	76.0	0.98	15	Clayton
CFO-FF-87-15	*Perca flavescens*	60.9	76.5	2.80	13	Clayton
CFO-FF-88-9	*Pimephales notatus*	101.25	75.4	2.88	36	Clayton
CFO-FF-88-10	*Perca flavescens*	100.78	76.0	1.36	29	Clayton
CFO-FF-88-11	*Fundulus diaphanus*	100.89	75.9	1.65	38	Clayton
CFO-FF-88-12	*Perca flavescens*	102.52	76.1	1.32	30	Clayton
CFO-FF-88-13	*Perca flavescens*	101.11	75.5	1.79	30	Chippewa Bay
CFO-FF-88-14	*Notropis hudsonius*	101.12	74.3	3.76	50	Chippewa Bay
CFO-FF-88-15	*Pimephales notatus*	102.46	72.6	2.58	32	Chippewa Bay
CFO-FF-88-16	*Fundulus diaphanus*	101.74	75.0	1.84	42	Chippewa Bay
SLRF1901	*Pimephales notatus*	116	78.5	3.08	40	Chippewa Bay
SLRF2904	*Pimephales notatus*	119	79.0	2.94	46	Chippewa Bay
SLRF3906	*Notropis atherinoides*	111	79.5	2.74	36	Chippewa Bay
SLRF4907	*Notropis atherinoides*	115	78.0	3.86	36	Chippewa Bay
SLRF59011	*Notropis atherinoides*	101	78.0	3.54	32	Clayton
SLR69012	*Pimephales notatus*	103	77.5	2.90	40	Clayton
SLR79013	*Notropis atherinoides*	105	78.0	3.72	45	Clayton
SLR89015	*Pimephales notatus*	101	77.0	3.96	32	Clayton

[a] See Fig. 1.

Table 3. Occurrence of organochlorine residues (ppm wet weight) in Common Tern eggs collected from the St. Lawrence River and Oneida Lake, New York, 1986 - 1989.

	Number with Residues and Range (in parentheses) St. Lawrence River				Oneida Lake
Compound	1986 (n=10)	1987 (n=11)	1988 (n=10)	1989 (n=5)	1989 (n=5)
Oxychlordane	10 (0.016 - 0.065)	11 (0.02 - 0.09)	10 (0.02 - 0.07)	ND	ND
Cis-chlordane	10 (0.017 - 0.037)	ND	ND	ND	ND
Trans-nonachlor	10 (0.022 - 0.047)	11 (0.04 - 0.11)	9 (ND - 0.100)	ND	ND
Heptachlor epoxide	10 (0.012 - 0.031)	ND	10 (0.01 - 0.04)	5 (0.01 - 0.04)	5 (0.02 - 0.06)
Methoxychlor	10 (0.054 - 0.170)	ND	ND	ND	ND
p,p'-DDE	10 (0.670 - 2.400)	11 (1.00 - 3.30)	10 (0.69 - 2.20)	ND	ND
o,p'-DDT	9 (ND - 0.042)	ND	ND	ND	ND
Dieldrin	10 (0.054 - 0.170)	11 (0.04 - 0.20)	10 (0.03 - 0.12)	5 (0.02 - 0.08)	(0.02 - 0.10)

—Continued—

Table 3. Continued

Compound	Number with Residues and Range (in parentheses) St. Lawrence River				Oneida Lake
	1986 (n=10)	1987 (n=11)	1988 (n=10)	1989 (n=5)	1989 (n=5)
PCB	10 (1.90 - 4.12)	11 (4.00 - 9.30)	10 (3.70 - 9.60)	5 (2.2 - 5.2)	5 (1.4 - 2.4)
Mirex	ND	11 (0.26 - 0.61)	10 (0.07 - 0.28)	5 (0.15 - 0.42)	5 (0.02 - 0.13)
Cis-Nonachlor	ND	ND	9 (ND - 0.06)	ND	ND
p,p'-DDD	ND	11 (0.03 - 0.08)	10 (0.02 - 0.11)	5 (0.01 - 0.07)	5 (0.03 - 0.03)
HCB	10 (0.016 - 0.052)	ND	10 (0.01 - 0.03)	5 (0.01 - 0.07)	5 (0.01 - 0.03)

ND Not Detected

Table 4. Comparison of mean DDE to PCB ratios between Common Tern eggs and forage fish collected from the St. Lawrence River, New York, 1986-1989.

Year	Common Tern	forage fish
1986	0.47 (n=10)	0.52 (n=2)
1987	0.29 (n=11)	0.30 (n=3)
1988	0.20 (n=10)	0.22 (n=7)
1989	0.24 (n=5)	————
1990	————	*
Grand mean	0.31 (n=36)	0.34 (n=12)

* no PCBs detected.

Table 5. Geometric mean concentration (ppm wet weight) and 95% confidence interval of organochlorine and aliphatic hydrocarbon residues in Common Tern eggs from the St. Lawrence River and Oneida Lake, New York 1986 - 1989.

	St. Lawrence River								Oneida Lake	
	1986		1987		1988		1989		1989	
Compound	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.
HCB	0.02	0.01-0.03		ND		ND	0.1	0.1-0.1	0.02	0.007-0.03
Oxychlordane	0.03	0.03-0.04	0.04	0.02-0.06		*		ND		ND
Heptachlordane	0.02	0.02-0.02		ND		*	0.02	0.01-0.04	0.04	0.02-0.06
chlordane	0.02	0.02-0.02		ND		ND		ND		ND
t-nonachlor	0.03	0.02-0.04	0.07	0.05-0.1	0.05	0.02-0.08		ND		ND
Methoxychlor	0.08	0.06-0.1		ND		ND		ND		ND
PCB	2.65	2.21-3.19	5.93	4.90-7.17		*	3.12	1.88-5.17	1.89	1.36-2.62
p,p'-DDE	1.22	0.97-1.54	1.71	1.32-2.22		*	0.76	0.02-0.08	0.53	0.38-0.73
p,p'-DDT	0.03	0.02-0.03		ND		ND		ND		ND
Mirex		ND	0.40	0.34-0.49	0.81	0.61-1.1	0.23	0.12-0.45	0.05	0.02-0.13
Dieldrin	0.03	0.02-0.03	0.09	0.07-0.13		*	0.04	0.02-0.08	0.03	0.007-0.14
p,p'-DDD		ND	0.05	0.04-0.07	0.03	0.02-0.04	0.02	0.008-0.06	0.03	0.03-0.03
n-pentadecane	0.04	0.01-0.12		ND	0.02	0.009-0.03		**		**
n-heptadecane	0.08	0.03-0.19		ND		*		**		**
n-dodecane	0.28	0.22-0.36		ND	0.02	0.02-0.03		**		**
n-tridecane		ND		ND	0.01	0.009-0.03		**		**
n-tetradecane		ND		ND	0.04	0.03-0.06		**		**
n-hexadecane		ND		ND	0.04	0.02-0.08		**		**
n-octadecane		ND		ND	0.08	0.06-0.1		**		**
n-nonadecane		ND		ND		*		**		**

—— Continued ——

Table 5. Continued

	St. Lawrence River								Oneida Lake	
	1986		1987		1988		1989		1989	
Compound	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.
pristane		ND		ND	0.15	0.09-0.23		**		**
phytane		ND		ND	0.02	0.02-0.02		**		**
n-eicosane		ND		ND	0.03	0.02-0.06		**		**

ND Not Detected.
* see Table 6.
** Aliphatic compounds not analyzed.

Table 6. Comparison by Mann-Whitney Test of geometric mean concentrations and 95% confidence intervals of organochlorine and aliphatic hydrocarbon residues in Common Tern eggs collected from Clayton and Chippewa Bay, New York, 1988.

	Clayton (n=5)		Chippewa Bay (n=5)		
Compound	Mean	(95% C.I.)	Mean	(95% C.I.)	*P*
Dieldrin	0.11	(0.086 - 0.128)	0.052	(0.033 - 0.079)	< 0.01
p,p DDE	1.7	(1.4 - 2.2)	1.0	(0.75 - 1.4)	< 0.01
PCB	8.1	(6.7 - 9.7)	5.2	(4.0 - 6.7)	< 0.01
DDE/PCB ratio	0.21	(0.20 - 0.23)	0.19	(0.19 - 0.20)	< 0.05
Heptachlor epoxide	0.03	(0.02 - 0.04)	0.015	(0.009 - 0.02)	< 0.05
Oxychlordane	0.05	(0.03 - 0.07)	0.02	(0.02 - 0.03)	< 0.05
Heptadecane	0.21	(0.13 - 0.34)	0.10	(0.06 - 0.17)	< 0.05
Nonadecane	0.10	(0.06 - 0.17)	0.02	(0.02 - 0.03)	< 0.05

Table 7. Occurrence of organochlorine residues (ppm wet weight) in forage fish collected from the St. Lawrence River, New York, 1986 - 1990.

	Number of Residues and Range (in parentheses)			
Compound	1986(n=2)	1987(n=6)	1988(n=8)	1990(n=8)
p,p'-DDE	2 (0.03 - 0.04)	6 (0.01 - 0.03)	8 (0.01 - 0.06)	8 (0.01 - 0.06)
p,p'-DDD	ND	ND	ND	7 (ND - 0.01)
PCB	2 (0.05 - 0.09)	3 (ND - 0.19)	7 (ND - 0.36)	ND
trans-nonachlor	ND	ND	ND	7 (ND - 0.01)

ND Not Detected.

Table 8. Geometric mean concentration (ppm wet weight) and 95% confidence interval of organochlorine residues in forage fish collected from the St. Lawrence River, New York, 1986 - 1990.

	1986 (n=2)		1987 (n=6)		1988 (n=8)		1990 (n=8)	
Compound	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.
t-nonachlor	ND	------	ND	------	ND	------	0.009	0.007-0.011
p,p'-DDE	0.003	0.006-0.21	0.02	0.014-0.031	0.031	0.018-0.053	0.035	0.023-0.055
p,p'-DDD	ND	------	ND	------	ND	------	0.009	0.007-0.011
Total PCB	0.067	0.002-2.84	0.02	0.004-0.106	0.116	0.036-0.372	ND	------

ND Not detected

Table 9. Occurence of elemental residues (ppm dry weight) in Common Tern eggs collected from the St. Lawrence River and Oneida Lake, New York, 1986 - 1989.

	Number of Residues and Range (in parentheses)				
	St. Lawrence River				Oneida Lake
Element	1986(n=9)	1987(n=11)	1988(n=10)	1989(n=5)	1989(n=5)
Aluminum	9 (0.0 - 5.2)	10 (ND - 9.2)	10 (0.3 - 1.7)	ND	ND
Beryllium	9 (0.01 - 0.05)	ND	ND	ND	ND
Cadmium	ND	6 (ND - 0.04)	9 (ND - 0.19)	ND	ND
Chromium	5 (ND - 0.30)	ND	ND	5 (0.21 - 0.84)	5 (0.21 - 0.81)
Copper	9 (2.87 - 4.11)	11 (2.33 - 2.85)	10 (2.62 - 3.2)	5 (2.89 - 3.45)	5 (2.82 - 6.61)
Iron	9 (91.30 - 151.0)	11 (92.00 - 133.0)	10 (108.0 - 138.0)	5 (88.31 - 146.22)	5 (97.05 - 117.76)
Magnesium	ND	ND	ND	5 (426.58 - 492.04)	5 (408.32 - 502.34)
Manganese	9 (1.6 - 2.6)	11 (1.6 - 2.95)	10 (1.4 - 3.05)	5 (1.51 - 2.45)	5 (2.38 - 3.88)
Mercury	9 (1.08 - 1.9)	11 (1.02 - 1.9)	10 (0.97 - 2.5)	5 (1.55 - 2.54)	5 (1.28 - 1.69)
Selenium	9 (2.9 - 3.3)	11 (2.6 - 3.3)	10 (2.6 - 3.5)	5 (3.10 - 3.56)	5 (2.55 - 3.39)
Strontium	ND	ND	ND	5 (0.14 - 0.27)	5 (0.65 - 1.00)
Zinc	9 (55.5 - 69.4)	11 (56.6 - 76.1)	10 (54.30 - 68.50)	5 (53.58 - 70.96)	5 (56.36 - 68.71)

ND Not Detected.

Table 10. Geometric mean concentration (ppm dry weight) and 95% confidence interval of elemental residues in Common Tern eggs from the St. Lawrence River and Oneida Lake, New York, 1986 - 1989.

	St. Lawrence River								Oneida Lake	
	1986(n=10)		1987(n=11)		1988(n=10)		1989(n=5)		1989(n=5)	
Compound	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.
Aluminum	2.2	1.4-3.6	1.4	0.76-2.6	0.58	0.38-0.88	a		a	
Beryllium	0.02	0.01-0.04	ND		ND		ND		ND	
Cadmium	ND		0.02	0.02-0.03	0.04	0.03-0.06	ND		ND	
Chromium	0.1	0.07-0.2	ND		ND		0.5	0.3-1.0	0.44	0.19-1.0
Copper	3.25	2.96-3.58	2.56	2.44-2.69	2.8	2.66-2.95	3.2	2.76-3.51	3.52	2.27-5.48
Iron	114.1	100.1-130.1	112.2	103.9-121.3	117.5	111.7-123.6	112.5	88.72-142.6	104.7	95.75-114.5
Mercury	1.6	1.3-1.8	1.4	1.2-1.6	1.4	1.2-1.7	1.9	1.4-2.6	1.5	1.2-1.9b
Magnesium	c		c		c		469.89	435.2-507.36	458.14	416.26-504.24
Manganese	2.1	1.8-2.3	2.2	1.9-2.4	2.1	1.8-2.4	2.0	1.6-2.6	2.9	2.28-3.7
Selenium	3.1	3.0-3.2	3.0	2.8-3.1	3.1	3.0-3.3	3.2	3.0-3.5	3.0	2.6-3.4
Strontium	c		c		c		0.211	0.15-0.298	0.871	0.701-1.08
Zinc	61.55	52.23-72.52	66.66	53.11-83.68	60.49	57.42-63.73	61.76	54.17-70.14	62.23	55.47-69.82

ND Not Detected
a Not included because of analytical difficulties
b (n=4)
c Not included in the analyses

Table 11. Occurrence of elemental residues (ppm dry weight) in forage fish collected from the St. Lawrence River, New York, 1986 - 1990.

	Number of Residues and Range (in parentheses)			
Element	1986* (n=2)	1987 (n=6)	1988 (n=8)	1990 (n=8)
Aluminum	2 (25.0 - 32.0)	6 (21.0 - 203.0)	8 (17.0 - 278.0)	8 (7.0 - 379.0)
Arsenic	2 (0.20 - 0.30)	5 (ND - 0.47)	5 (ND - 0.42)	ND
Barium	A	A	A	8 (6.1 - 14.0)
Cadmium	2 (0.09 - 0.10)	6 (0.04 - 0.17)	8 (0.05 - 0.14)	ND
Chromium	2 (0.4 - 0.7)	6 (0.1 - 4.2)	8 (1.0 - 4.0)	ND
Copper	2 (1.8 - 2.2)	6 (2.9 - 8.4)	8 (3.1 - 11.0)	8 (2.5 - 4.0)
Iron	2 (53.4 - 67.3)	6 (66.6 - 154.0)	8 (69.9 - 529.0)	8 (52.0 - 383.0)
Mercury	2 (0.15 - 0.18)	6 (0.13 - 0.25)	8 (0.20 - 0.29)	8 (0.16 - 0.26)
Magnesium	A	A	A	8 (1300.0 - 1420.0)
Manganese	2 (8.5 - 8.7)	6 (6.8 - 23.0)	8 (6.8 - 28.0)	8 (7.3 - 16.0)
Nickel	2 (0.20 - 0.20)	5 (ND - 2.2)	8 (9.0 - 153.0)	ND
Selenium	2 (2.1 - 2.6)	6 (1.7 - 2.6)	8 (1.7 - 2.5)	6 (ND - 8.0)
Strontium	A	A	A	8 (43.6 - 53.9)
Zinc	2 (197.0 - 205.0)	6 (94.0 - 273.0)	8 (102.0 - 237.0)	8 (148.0 - 199.0)

* analyzed in 1987
A Not Analyzed
ND Not Detected

Table 12. Geometric mean concentration (ppm dry weight) and 95% confidence interval of elemental residues in forage fish collected from the St. Lawrence River, New York, 1986 - 1990.

	1986 (n=2)		1987 (n=6)		1988 (n=8)		1990 (n=8)	
Element	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.	Mean	95% C.I.
Aluminum	28.31	5.83-137.44	68.08	31.02-149.4	54.45	25.96-114.19	51.4	16.29-162.19
Arsenic	0.245	0.019-3.215	0.28	0.15-0.54	0.13	0.06-0.29	ND	
Barium	ND		ND		ND		9.06	6.5-12.63
Cadmium	0.095	0.048-0.186	0.079	0.046-0.135	0.09	0.06-0.14	ND	
Chromium	0.53	0.015-18.8	0.769	0.208-2.84	2.09	1.39-3.15	ND	
Copper	1.99	0.55-7.21	3.94	2.68-5.81	4.61	3.17-6.72	3.21	2.75-3.73
Iron	59.98	13.89-259.0	95.06	67.59-133.69	137.72	81.21-233.56	107.89	57.99-200.73
Magnesium	ND		ND		ND		1352.07	1315.75-1389.39
Manganese	8.59	2.24-33.0	9.44	5.88-15.16	13.37	9.03-19.78	10.26	7.94-13.25
Mercury	0.164	0.051-0.53	0.18	0.14-0.24	0.25	0.22-0.28	*	
Nickel	0.2	0.2-0.2	0.637	0.247-1.64	45.29	19.26-106.49	ND	
Selenium	2.34	0.61-8.98	1.91	1.62-2.56	2.11	1.84-2.42	1.87	0.29-12.15
Strontium	ND		ND		ND		*	
Zinc	200.91	154.4-261.43	138.68	86.83-221.47	146.55	68.38-314.12	169.04	154.94-184.43

ND Not Detected.
* see Table 13.

Table 13. Comparison of geometric mean concentration (ppm dry weight) and 95% confidence intervals of mercury and strontium in forage fish collected from Clayton and Chippewa Bay, New York, 1990.

	Clayton		Chippewa Bay		
Element	Mean	(95% C.I.)	Mean	(95% (C.I.)	*P*
Mercury	0.26	(0.17 - 0.27)	0.17	(0.16 - 0.19)	< 0.05
Strontium	50.4	(46.5 - 54.6)	44.6	(43.2 - 46.0)	< 0.05

Table 14. Occurrence of aliphatic hydrocarbon residues (ppm wet weight) in Common Tern eggs collected from the St. Lawrence River, New York, 1986 - 1988.

	Number with Residues and Range (in parentheses)		
	St. Lawrence River		
Compound	1986 (n=10)	1987 (n=11)	1988 (n=10)
n-dodecane	10 (0.18 - 0.51)	ND	10 (0.01 - 0.03)
n-pentadecane	7 (ND - 0.200)	ND	7 (ND - 0.05)
n-heptadecane	9 (ND - 0.30)	ND	10 (0.07 - 0.31)
n-tridecane	ND	ND	9 (ND - 0.02)
n-tetradecane	ND	ND	10 (0.03 - 0.09)
n-hexadecane	ND	ND	9 (ND - 0.100)
pristane	ND	ND	10 (0.06 - 0.46)
n-octadecane	ND	ND	10 (0.05 - 0.12)
phytane	ND	ND	10 (0.02 - 0.03)
n-nonadecane	ND	ND	6 (ND - 0.03)
n-eicosane	ND	ND	9 (ND - 0.06)

Table 15. Comparison of mean concentration of mirex and DDE to PCB ratios found in Common Tern eggs collected from the St. Lawrence River and Oneida Lake, New York, 1989.

Compound	St. Lawrence River	Oneida Lake	*P*
Mirex	0.24	0.05	< 0.01
p,p'-DDE:PCB	0.24	0.40	< 0.01

APPENDIX A

BIRD EGG AND FISH SAMPLE PREPARATION PROTOCOLS

Harvesting egg contents from shells provides critical information about embryo development, and measurements allow for interpretation of analytical results. Think of the process as being performed in three stages, 1) whole egg measurements, 2) egg harvest, and 3) eggshell thickness measurements.

The supplies needed for the procedures include:

1. WHOLE EGG MEASUREMENTS	--	distilled-deionized water, volumeter, egg candler, Kimwipes, laboratory balance (to 0.05 g increments), vernier caliper (graduated to 0.01mm).
2. EGG HARVEST	--	glass jars of appropriate size (chemically-cleaned and with TFE cap-liners), chemically-rinsed scalpel, lead pencil, and technical pen.
3. SHELL THICKNESS MEASUREMENTS	--	dial micrometer with rounded contacts (graduated to 0.01 mm).

<u>EGG MEASUREMENT PROCEDURE</u>:

1. If possible, eggs should be candled to determine if cracks are present in the shell. Any cracked egg should not be rinsed or immersed in water as this may contaminate the sample.

2. Store eggs in a refrigerator if they cannot be processed immediately after collection. DO NOT FREEZE whole eggs since this will crack the shell.

3. If an egg is not cracked and is dirty (soil, feces) it should be cleaned with a Kimwipe and distilled-deionized water that is at, or near the temperature of the egg.

4. Write the sample ID number on both ends of the eggshell with a dull pencil (both IDs must be legible).

5. Record any remarkable characteristics of the egg (e.g. cracked, dented, discolorations, small in size, etc.).

6. Record the MASS (g) OF THE WHOLE EGG, then measure the

LENGTH (mm) and BREADTH (mm) of the egg with calipers at their greatest dimensions. (To obtain an accurate measurement of length, one must ensure that the caliper jaws are parallel to the longitudinal axis of the egg. For the breadth measurement, the jaws must be held perpendicular to the longitudinal axis of the egg).

7. Determine and record the EGG VOLUME (cm^3), the method of choice will depend on whether the shell is intact or cracked.

   A. INTACT SHELL: For eggs with intact shells, determine the EGG VOLUME using the water displacement technique outlined below.

      Place a volumeter next to and above the pan of a laboratory balance. Set a collection vessel on the balance's pan under the side arm of the volumeter. Next, place a wire loop in the volumeter. Fill the volumeter with distilled-deionized water until it flows freely from the volumeter side arm (REMEMBER, the temperature of the water should be as close to the temperature of the egg as possible). When the water stops flowing, empty the receptacle and return it to the balance pan. Tare the water receptacle. Gently raise the wire loop and place the egg on it. Gently lower the egg until it is completely submersed (lower the egg as quickly as possible without overflowing the volumeter, or breaking the egg). The weight of the displaced water equals the volume (cmm^3) of the egg. Repeat this procedure three (3) times for each egg and report the average value.

   B. CRACKED SHELL: For eggs that are cracked or dented, EGG VOLUME is estimated using the LENGTH and BREADTH measurements and an equation from the published literature (e.g. Westerskov 1950, and Stickel *et al.* 1973).

EGG HARVEST:

1. For eggs with a strong odor (indicating advanced decomposition of the contents), it is advisable to vent the egg before attempting to open it (explosions are possible). With safety glasses in in place, gently insert a chemically-clean needle into the blunt end of the egg. Use gentle but steady pressure to pierce the shell.

2. Tare a chemically-clean jar and loosen the lid. Rest the egg lengthwise on an appropriate surface (compatible with the analyses

requested). Using a sharp scalpel, gently score the egg about it's equator. Apply gentle, steady pressure and make several rotations around the egg. Once through the shell, insert the tip of the scalpel blade to cut the membrane and separate the two halves. Cut 1/2 - 2/3 the distance around the egg. Invert the egg while pulling apart the shell halves and pour the contents into the opened jar. If necessary use a chemically clean teflon spatula to scrape any remaining contents into the jar (BE CAREFUL not to tear the shell membrane when using spatula).

3. Record the EGG CONTENTS MASS (g).

4. Visually inspect the egg contents. Record presence or absence of an embryo, estimated age of embryo, abnormalities, etc.

5. Label jar with SAMPLE ID and SAMPLE MASS (place one label on the lid and the other on the jar itself), and immediately store the sample in the freezer.

6. Rinse the interior of the shell halves with tap water being careful not to tear the membrane, or erase the sample IDs. After the shells dry, use a technical pen to remark the shells with their sample IDs. Store the shells in a cool dry place for at least 30 days, or until they have attained a constant mass. (Recycled egg cartons serve as excellent storage containers for egg shells. One tip to ensure that shells do not migrate from their respective compartments, is to place a folded sheet of paper over the shells before closing the carton.

SHELL THICKNESS MEASUREMENT:

1. Determine the EGGSHELL MASS (to nearest 0.001 g) of dried shells.

2. Measure EGGSHELL THICKNESS using a dial micrometer with rounded contacts. Take thickness measurements of each shell-half along the equator at five places. Report the average of all TEN measurements as the final thickness measurement. If the membrane has separated from the shell, take measurements without the membrane but be sure to make note of this on the data sheet.

FORAGE FISH

1. Place fish collected in seine or dip net directly into hexane rinsed aluminum foil. Wrap in waterproof plastic bag and store on cracked ice until sample preparation the same day.

2. Prepare single species composite samples as follows:

    1. Remove fish from foil wrap using chemically clean, stainless steel forceps. Rinse fish with glass distilled water to remove any extraneous materials and place on tared hexane rinsed foil.

    2. Record the number of fish required to obtain a minimum sample mass of 100 g.

    3. Place fish in an appropriately sized, chemically-clean glass jar (with TFE cap-liner). Label, seal lid with teflon tape, enclose in plastic bag, and store frozen until shipped to the analytical laboratory.

    4. Preserve several fish specimens by fixing with 10 % formalin and then store them in 70 % ethyl alcohol for species identification or confirmation.

APPENDIX B

RISK ASSESSMENT

Risk Assessment for the Biomonitoring and Assessment of Environmental Contaminants in breeding Common Terns of the St. Lawrence River, New York

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The simple hazard assessment model developed by Kubiak and Best (1991) was used in assessing toxicological risks to Common Terns using the St. Lawrence River. The model used the lowest observed adverse effect levels (LOAEL) and no observed adverse effect levels (NOAEL) of contaminants to assess wildlife health, using the following basic components:

- the degree of exposure of an individual species most sensitive lifestage and the endpoint above laboratory or field derived NOAEL/LOAEL data of a similar lifestage and endpoint (exceedance over NOAEL/LOAEL),
- the degree of magnification of a contaminant from forage to target organ/egg (forage to organ/egg biomagnification factor, BMF), and the
- forage contaminant concentration.

To obtain a reasonable amount of protection for the most sensitive endpoint, the exceedance over NOAEL should be less than 1 (Kubiak and Best 1991). To determine the multiple by which the sensitive endpoint exceeds the NOAEL, one of two approaches may be used. In the first approach, the environmental concentration of a contaminant in the sensitive endpoint can be divided by the derived residue NOAEL/LOAEL to determine exceedance over NOAEL (Equation 1); concentrations of contaminants from locally caught forage can then be used to determine the target forage concentration necessary to obtain a reasonable protective endpoint when the exceedance over NOAEL is greater than one. This is accomplished by dividing the measured forage concentration by the exceedance over NOAEL (Equation 2).

Equation 1

$$\frac{\text{[wildlife organ/egg]}}{\text{[derived NOAEL/LOAEL]}} = \text{exceedance over NOAEL}$$

Equation 2.

$$\frac{\text{[measured forage]}}{\text{exceedance over NOAEL}} = \text{[Target forage]}$$

The second approach uses the derived dietary NOAEL/LOAEL as the target environmental forage concentration. This target forage concentration is divided into the environmental contaminant concentration measured in the locally caught forage to determine the exceedance over NOAEL (Equation 3).

Equation 3

$$\frac{[\text{measured forage}]}{[\text{target forage}]} = \text{exceedance over NOAEL}$$

The NOAEL and LOAEL concentrations of contaminants to be used for this risk assessment are summarized in Table B1. The avian effect levels are derived from egg residues (Tables 5, 6, and 10), therefore equation 1 was used to determine if there was an exceedance of the effect levels. If the reported level is a LOAEL, it was assumed that 10% of that level is the NOAEL.

All eggs collected from the St. Lawrence River and Oneida Lake between 1986 and 1989 exceeded the NOAELs for the four compounds (Table B2). The LOAEL for DDE was exceeded for eggs collected from the St. Lawrence River between 1986 and 1988, except for eggs from the Chippewa Bay area in 1988 which met the LOAEL. In 1988, the eggs collected from the Clayton area on the St. Lawrence River exceeded the LOAEL for dieldrin. Oneida Lake eggs were closer to protective levels than St. Lawrence River eggs in 1989 though they were not truly protective as all the NOAELs were exceeded. Generally, 1988 was the least protective of the four years for the terns on the St. Lawrence River. The levels of dieldrin and PCBs were more protective in 1986 than later years on the river

Table B1 -- The NOAEL and LOAEL data (μg/g wet weight) to be used for determining the exceedance over NOAEL/LOAEL in avian eggs

Compound	NOAEL or LOAEL	Level	Organism Tested
Total PCBs	NOAEL	0.4	chicken[1]
DDE	LOAEL*	1.0	Bald Eagle[2]
Dieldrin	LOAEL*	0.1	Bald Eagle[2]
Mercury	NOAEL	0.5	mallard[3]

* Field derived
[1] Britton and Huston 1973
[2] Wiemeyer *et al.* 1984
[3] Heinz 1979

Table B2. The exceedance over NOAEL/LOAEL using Equation 1 for Common Tern eggs from the St. Lawrence River and Oneida Lake, New York collected between 1986 and 1989.

	St. Lawrence River				Oneida Lake
Compound	1986	1987	1988[a] (Clayton/Chippewa)	1989	1989
Total PCB	6.625	14.825	20.25/13.0	7.8	4.725
p,p'-DDE	1.22	1.71	1.7/1.0	0.76	0.53
p,p'-DDE*	12.2	17.1	17.0/10.0	7.6	5.3
Dieldrin	0.3	0.9	1.1/0.52	0.4	0.3
Dieldrin*	3.0	9.0	11.0/5.2	4.0	3.0
Mercury	3.2	2.8	2.8	3.8	3.0

ND = Not Detected
* NOAEL = 10% of LOAEL
[a] - See Table 6.

followed by 1989. This eludes to a possible release/resuspension episode occurring between these breeding seasons which caused an increase in contaminant availability on the river. This episode may have occurred only in the general region as tern eggs from the Niagara River (Table B3) seem to indicate an annual downward trend toward more protective levels during this time period instead of a surge with the exception of PCBs in 1987 (Karwowski 1991).

All four of these compounds are known to have adverse effects upon reproduction and behavior. As observed by Kubiak *et al.* 1987, the contaminant burdens in the eggs are not the only factors to effect reproductive outcome, extrinsic factors like parental attentiveness may also be impaired due to contaminant burdens. Though the overall productivity of the St. Lawrence River Common Tern population was increasing from 1986 to 1988, this reflected the increased use of man-made nest sites which encountered less predation than natural nest sites (Karwowski *et al.* In Review). The difference in predation related chick mortality may be partly attributed to contaminant burdens which caused a decreased in parental attentiveness. There is a need for studies which can identify more conclusively the behavioral effects of contaminants.

Table B3. The exceedance over NOAEL/LOAEL using Equation 1 for Common Tern eggs from the Niagara River, New York between 1986 and 1988.

Compound	1986	1987	1988
Total PCB	11.425	15.225	11.025
p,p'-DDE	1.25	0.91	0.6
p,p'-DDE*	12.5	9.1	6.1
Dieldrin	0.9	0.6	0.3
Dieldrin*	9.0	6.0	3.0
Mercury	3.9	1.56	2.54

* NOAEL = 10% of LOAEL

It is assumed that most of the contaminant burden in the Common Terns is accumulated from their diet. Therefore, forage contaminant burdens which would have been protective for the St. Lawrence River Common Tern population can be determined using Equation 2 (Table B4). The forage contaminant concentrations needed to decrease at least an order of magnitude for total PCBs, DDE, and mercury to be protective of the sensitive endpoint of the Common Terns. Dieldrin was not detected in any of the forage fish collected from the St. Lawrence River between 1986 and 1988.

Table B4. The calculated target forage concentrations (ppm wet weight) using Equation 2 for Common Tern eggs from the St. Lawrence River, New York between 1986 and 1989.

Compound	[measured forage] / [target forage] 1986	1987	1988[a]
Total PCB	0.067 / 0.01	0.002 / 0.001	0.118 / 0.006/0.008
p,p'-DDE	0.003 / 0.0025	0.02 / 0.01	0.031 / 0.02/0.031
p,p'-DDE*	0.003 / 0.0002	0.02 / 0.001	0.031 / 0.002/0.003
Dieldrin	ND	ND	ND
Mercury	0.164 / 0.05	0.18 / 0.06	0.25 / 0.09

ND = Not Detected in fish
* NOAEL = 10% of LOAEL
a - Clayton Area/Chippewa Bay Area significant differences in contaminant burdens detected.

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APPENDIX C

ANALYTICAL RESULTS

Available upon request from:

U.S. Fish and Wildlife Service
New York Field Office
3817 Luker Road
Cortland, New York 13045